Aerosol Mass Spectrometer (HR-ToF-AMS) In-Flight Aircraft Emissions Sampling

ACCESS-II Data Workshop

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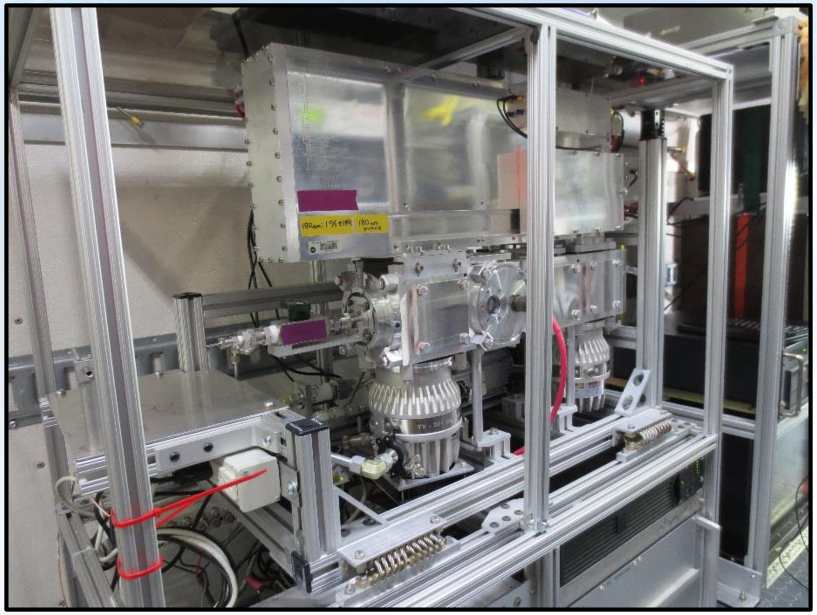
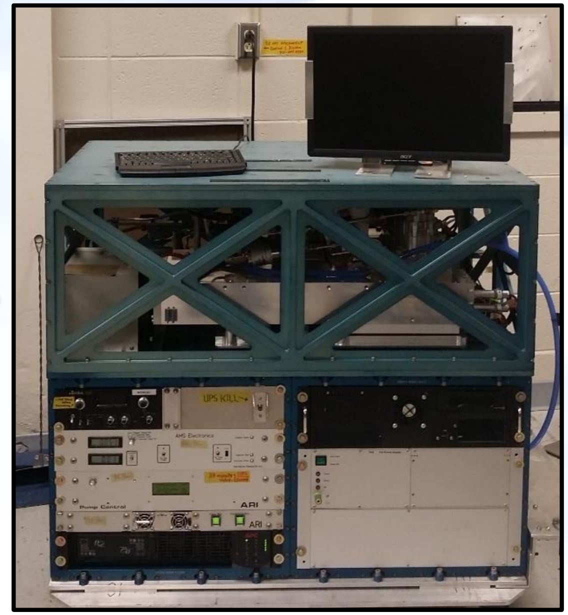
AMS Measurements: Objectives

1. Demonstrate the Aerodyne-AMS technique has sufficient sensitivity and time-response to make *in-flight* chemical composition measurements of the **volatile coatings** on aircraft soot emissions
2. Assess the variability in aerosol composition for different fuels:
    - Organic mass fraction
    - Organic oxidative state
3. Assess the contribution of lubrication oils to volatile organic emissions

AMS Repackaging for Flight

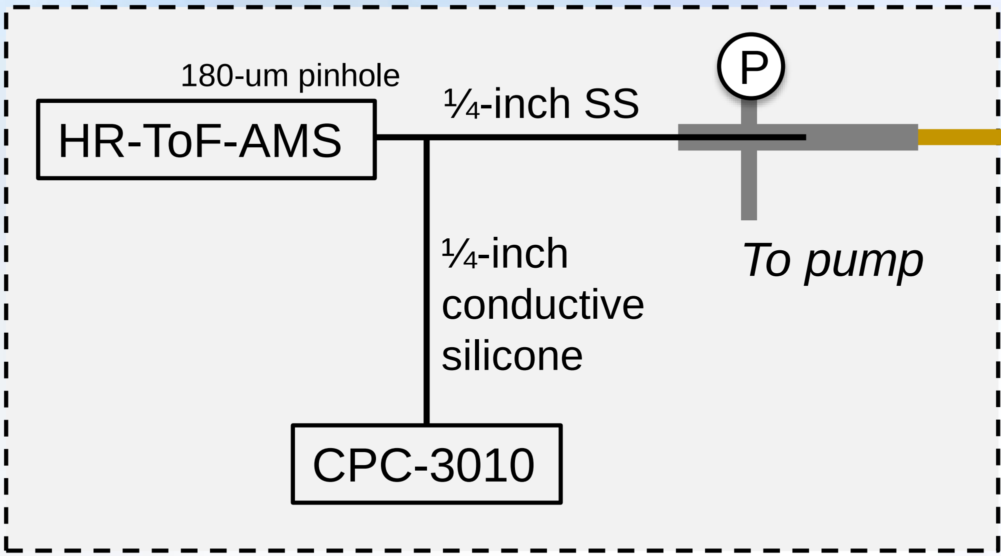


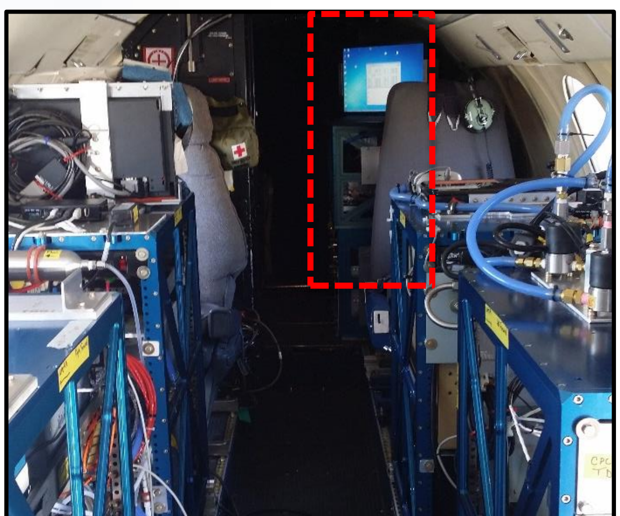


- 1-inch 80/20 structure not suitable for aircraft deployment
- 53-inch height cannot fit in smaller aircraft (NASA Falcon)
- Single-body mounting is not practical for integration
- Weight = 430 lbs.

- Custom, aircraft-rated hardware manufactured by WMD,Inc.
- Structural analysis provided
- Height reduced to 35-inch
- 3 independent structures can be integrated separately.
- Weight = 492 lbs. including CPC

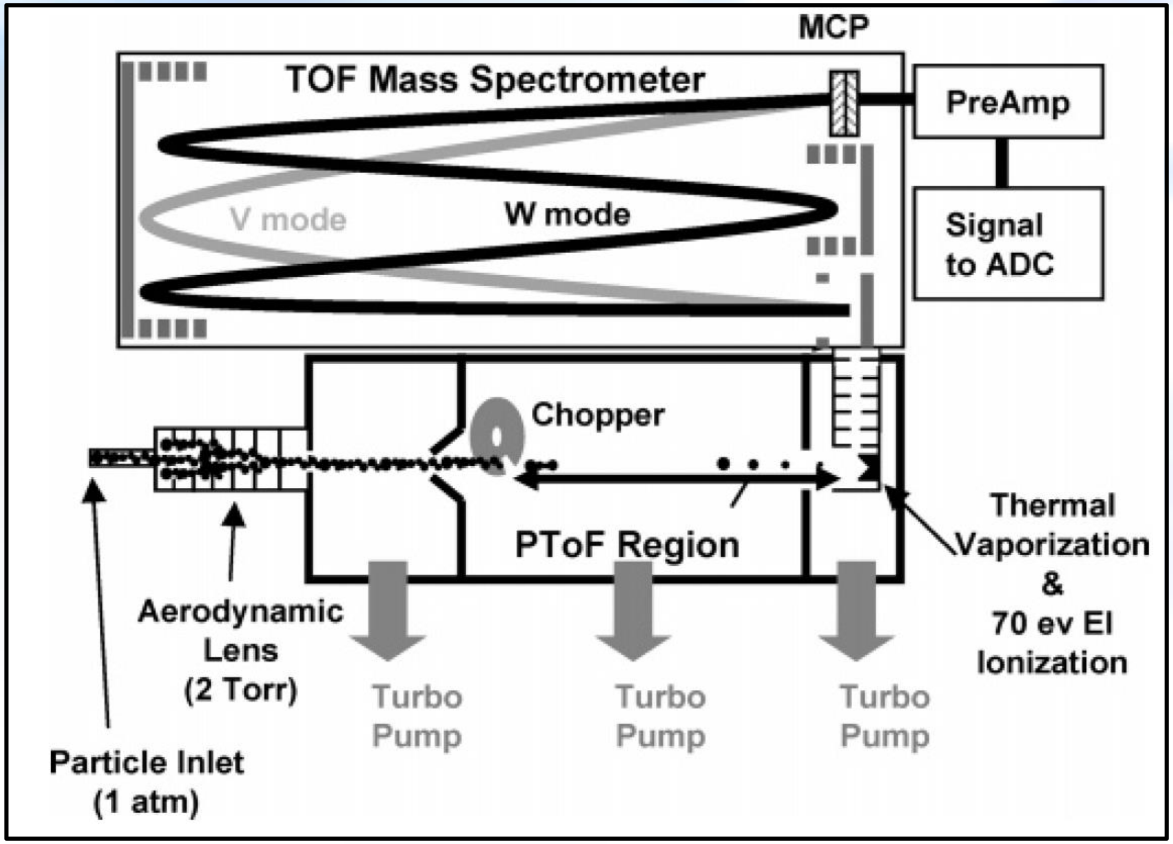
AMS Measurement Technique: Sampling





- Actively pressure-(P)-controlled at 180 torr (240mb)
- Conductive silicone tubing minimized to reduce AMS-artifact
- CPC used to decrease residence time during transport to AMS; also provides redundant measurement

AMS Measurement Technique



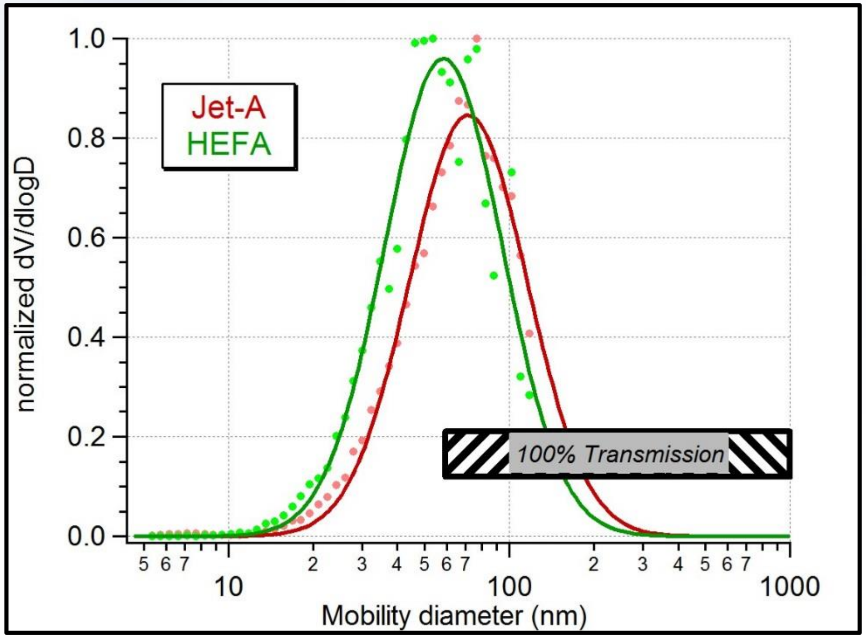
- Size-resolved chemical composition of non-refractory aerosols

AMS Measurement Technique: Limitations

- AMS lower-size limit is ~60nm diameter

  ** Suitable for most ambient observations of aerosol mass

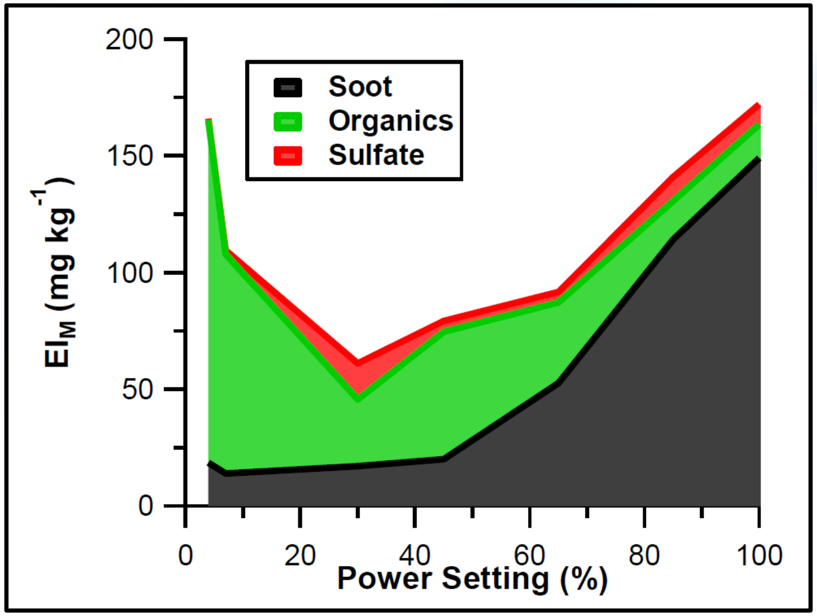
  ** Not optimal for observing aircraft emissions due to small particle size



- AMS only observes non-refractory aerosol mass, volatile at 600ºC

  ** suitable for ambient obs. when BC contribution is < 5%

  ** Not optimal for aircraft emissions depending on thrust



Reductions in aircraft particulate emissions due to the use of Fischer–Tropsch fuels

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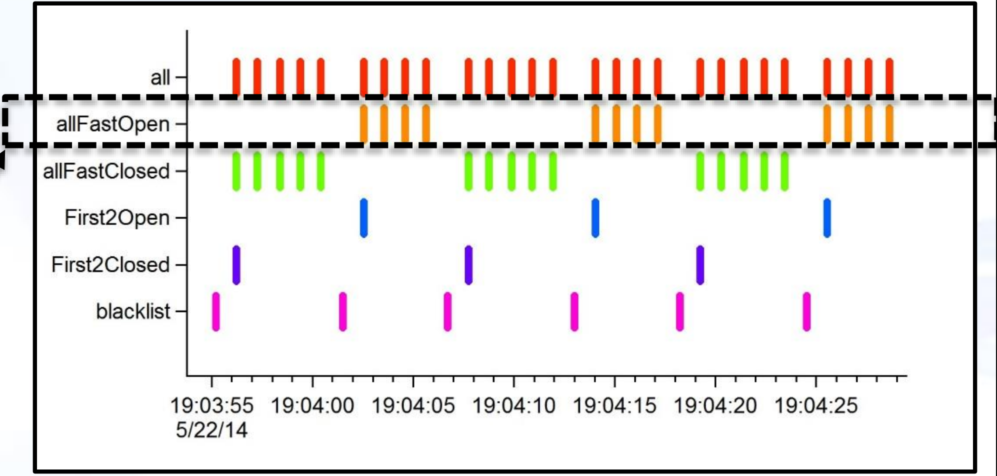
AMS Measurement Technique: FAST-MS Mode

- AMS is typically operated in alternating mode: cycling between open-MS, closed-MS, and pTOF modes (> 1 minute save rates)
  - Allows sufficient signal-to-noise
  - fast response is not necessary for ground applications
- ***Fast-mode*** saves data at 1 Hz
  - Sacrifices SNR for fast response
  - No particle sizing is obtained
  - Relies on ‘stable’ conditions for a 10-sec period to accurately calculate difference spectra and obtain particle-phase composition

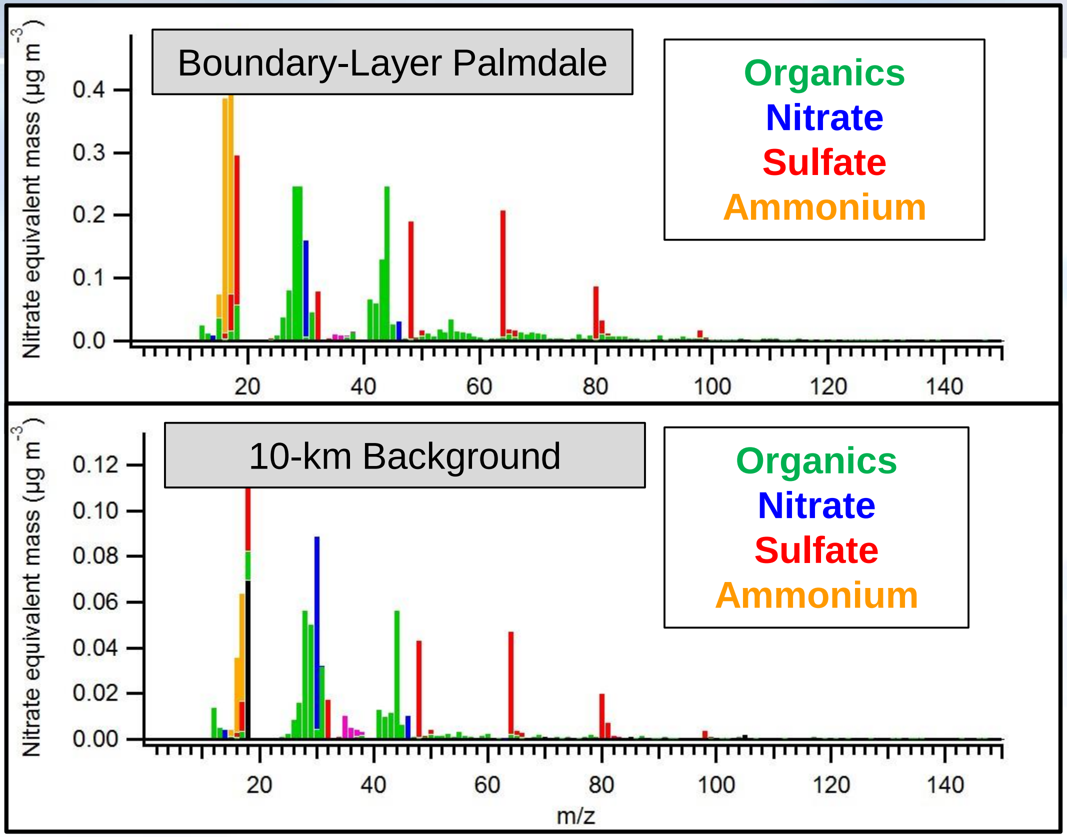
3 full measurement cycles



AMS Measurement Technique: MS Apportionment

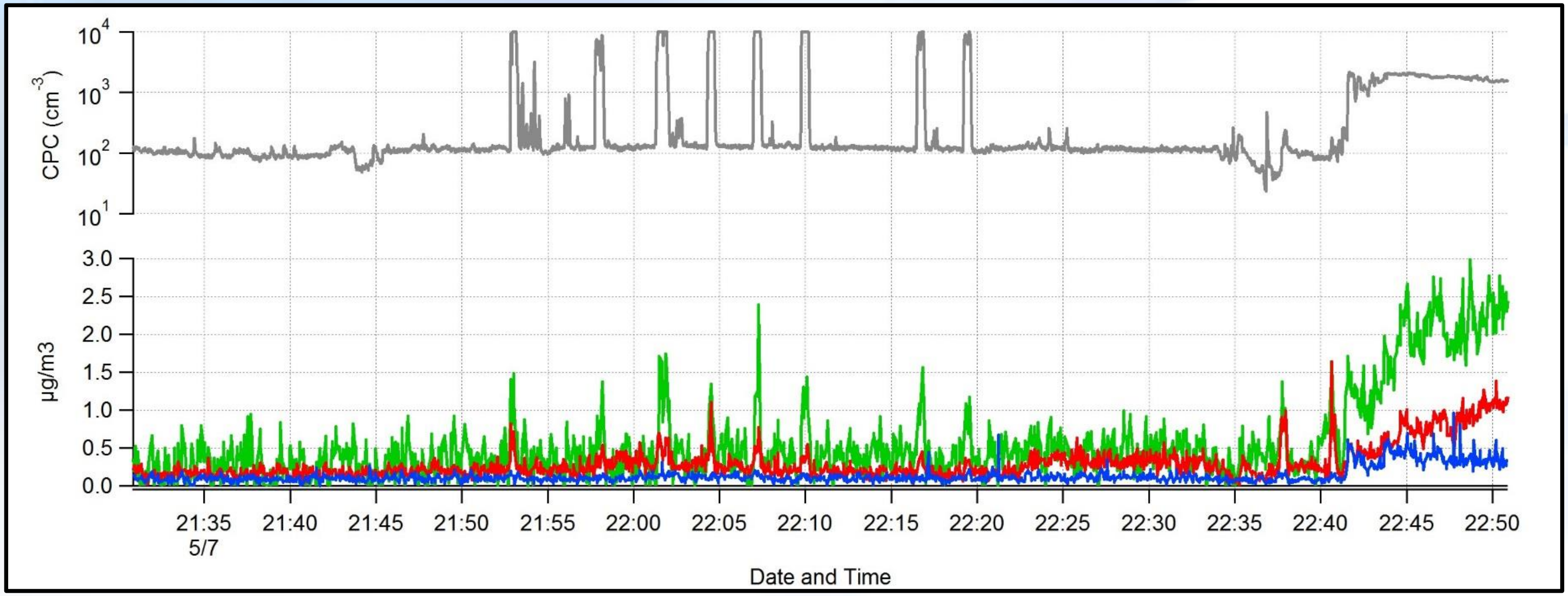
- AMS uses known fragmentation patterns to apportion mass-spectral peaks to common aerosol types

- m/z44 is typically dominant for ambient aerosol (oxidized organics).
  - m/z44 must be corrected using a measurement of CO_2 for aircraft emissions



- Generally similar contributions in free troposphere as BL
- Increased nitrate importance at low temp.

AMS Measurements: First Flight (5/7)



<u>Background Conditions</u>:

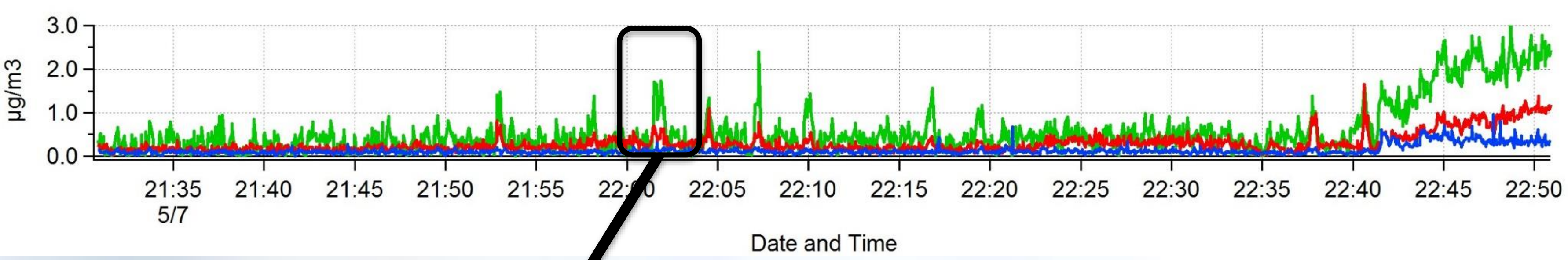
- 10^2 cm^{-3}
  - Organics = 0.28 ± 0.25 µg m^{-3}
  - Sulfate = 0.18 ± 0.06 µg m^{-3}
  - Nitrate = 0.09 ± 0.04 µg m^{-3}

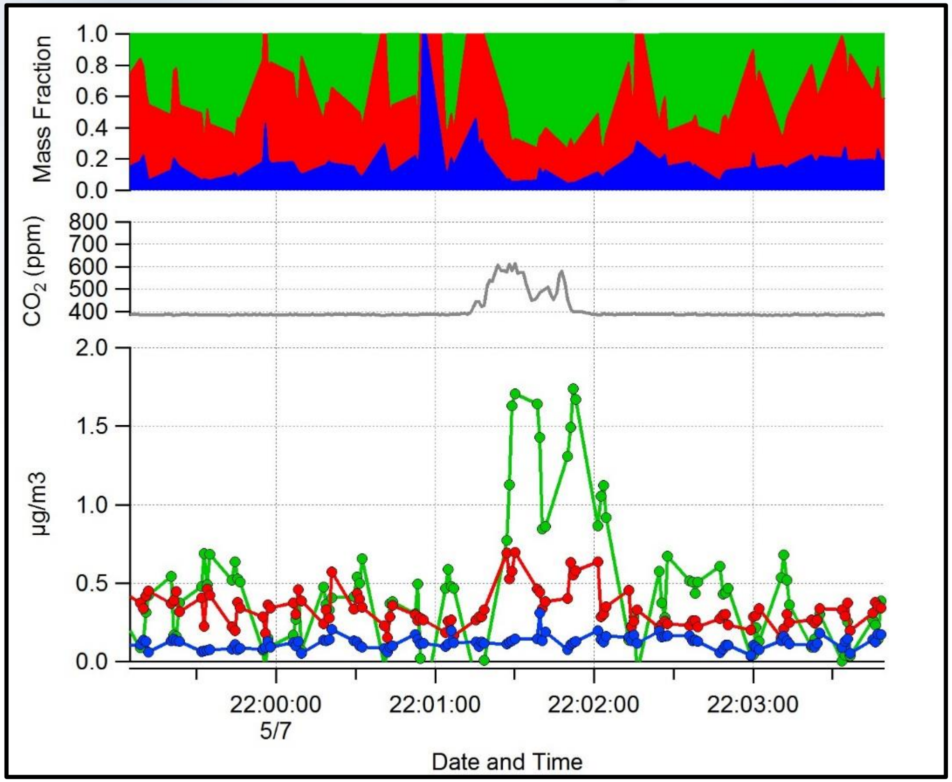
<u>Exhaust Plumes</u>:

- 10^4 cm^{-3}
  - Organics = 1.0 - 2.5 µg m^{-3}
  - Sulfate = 0.5 - 1.0 µg m^{-3}
  - Nitrate ~ 0.1 µg m^{-3}

Preliminary

AMS Measurements: First Flight





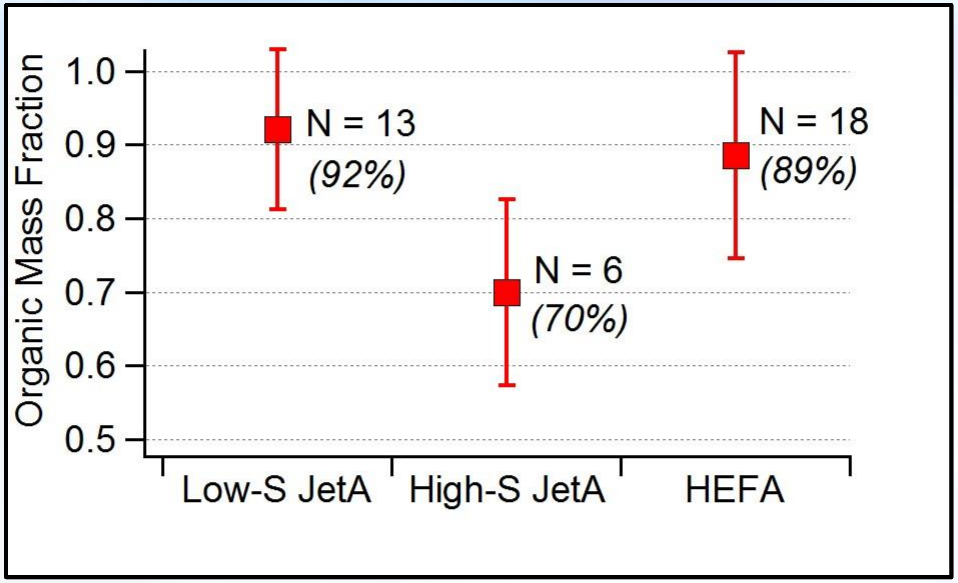
<u>Background</u>:

- 386 ppm CO_2
  - Organics ~ 39% (mass)

<u>JP-8 Plume</u>:

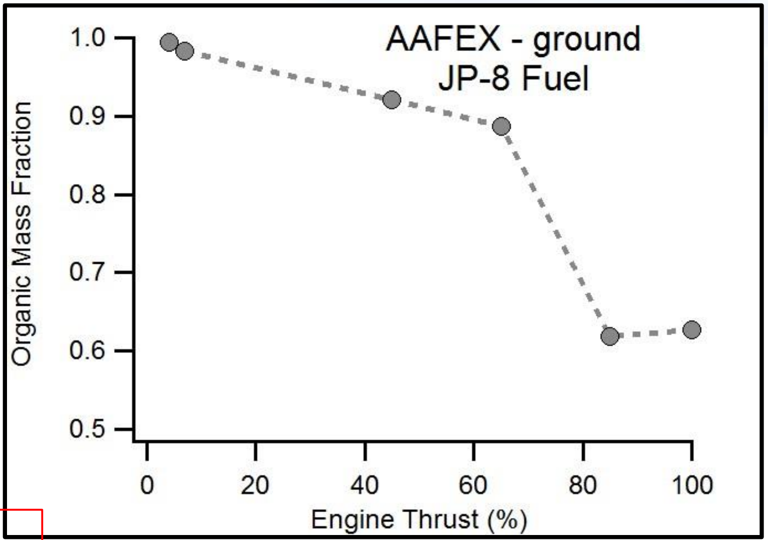
- 4 save periods
- Δ 150 ppm CO_2
  - Organics ~ 67% (mass)

AMS Measurements:
Fuel Properties Alter Aerosol Composition



ACCESS-II

	Low-S JetA	High-S JetA	HEFA Blend
Sulfur (ppm)	20	426	9

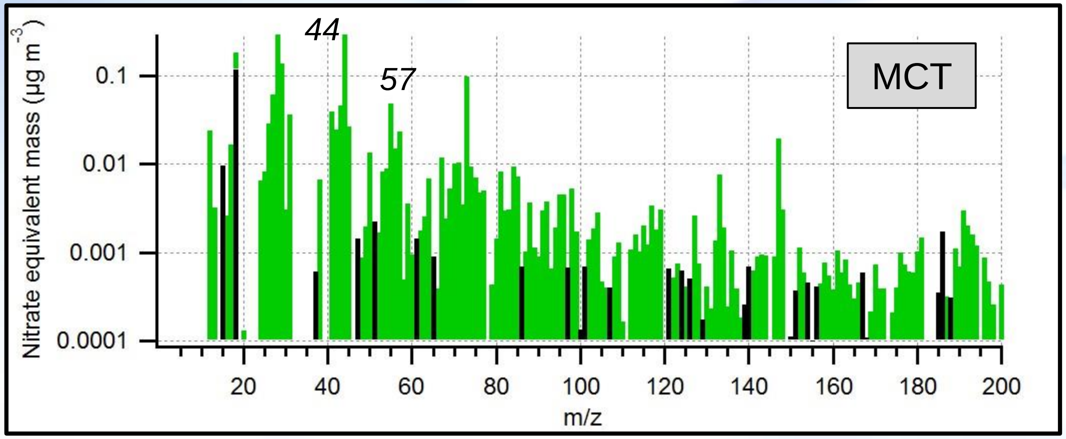


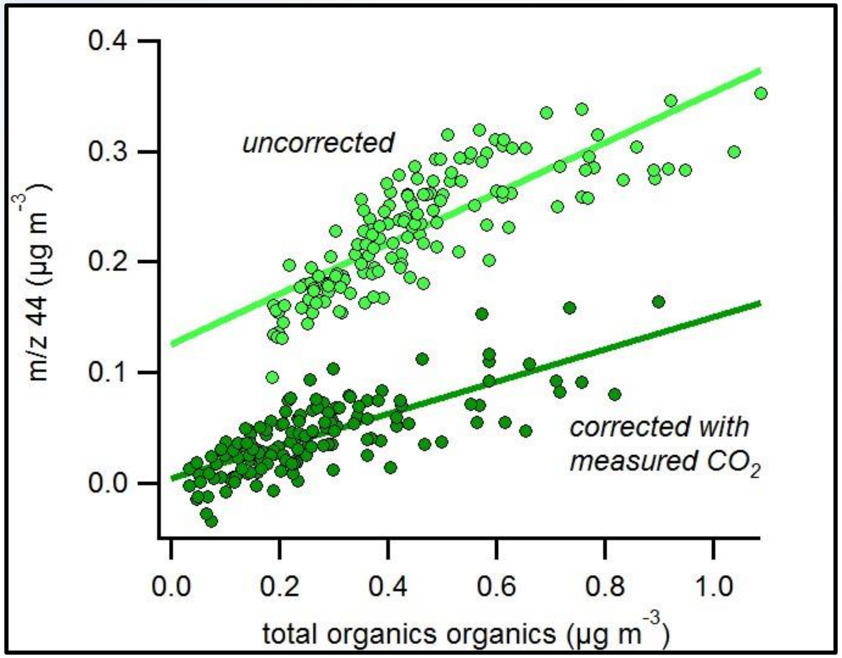
- Organic compounds dominate the Low-S JetA and HEFA-blend emissions (~90%)
- Sulfate contribution is increased for JetA
- Results are qualitatively consistent with ground-based measurements at higher engine thrust

Preliminary

AMS Measurements: Extent of Organic Oxidation

- Engine-2
- 5/22 Flight
- Fuel = HighS JetA





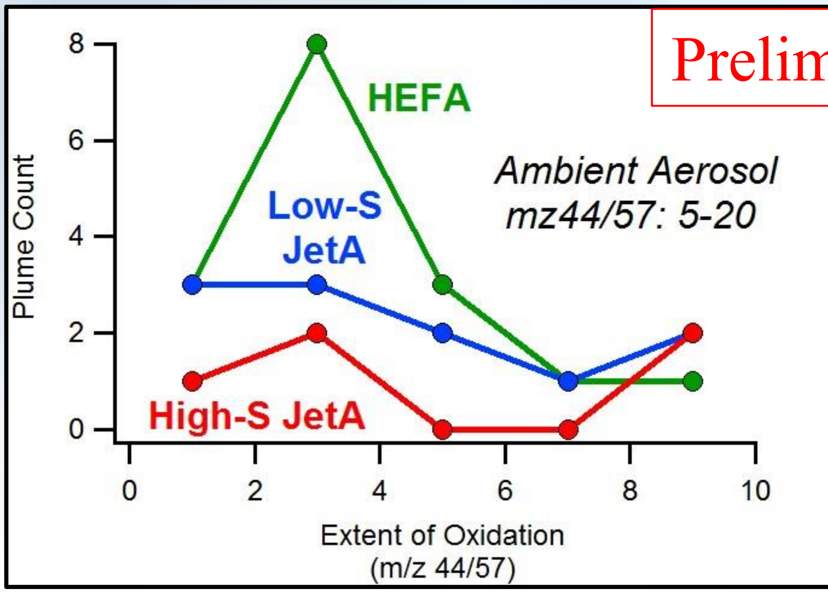
- m/z44 (CO_2^+) used as a tracer for oxidized organics
- Enhanced CO_2 from combustion significantly impacts organic aerosol quantification
- After correction, organic aircraft emissions still contain oxygenated compounds (15% of organic signal)
- Ratio of m44 to m57 is a general indicator of the state of oxidation

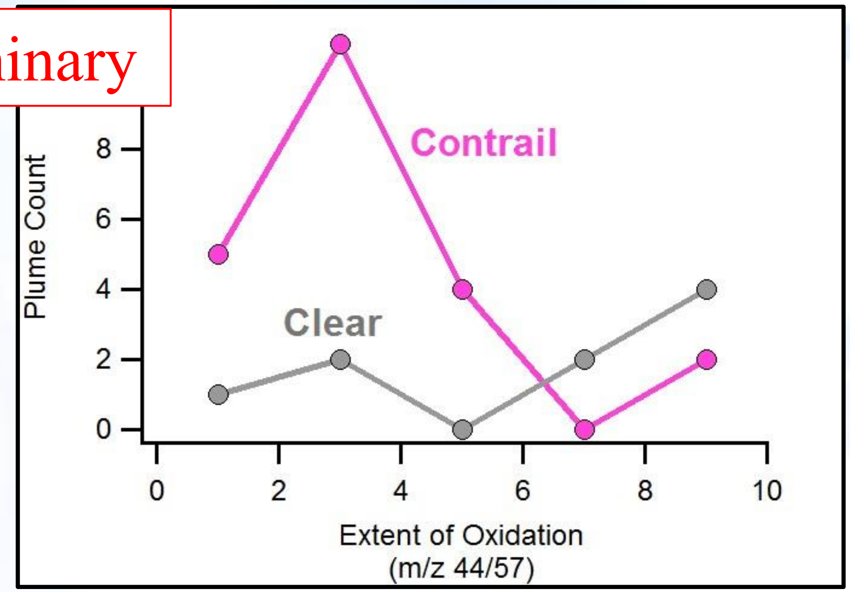
AMS Measurements: Aerosol Extent of Oxidation

CO_2^+ $C_4H_9^+$

- m/z 44/57 used as a proxy for the extent of organic oxidation

Preliminary

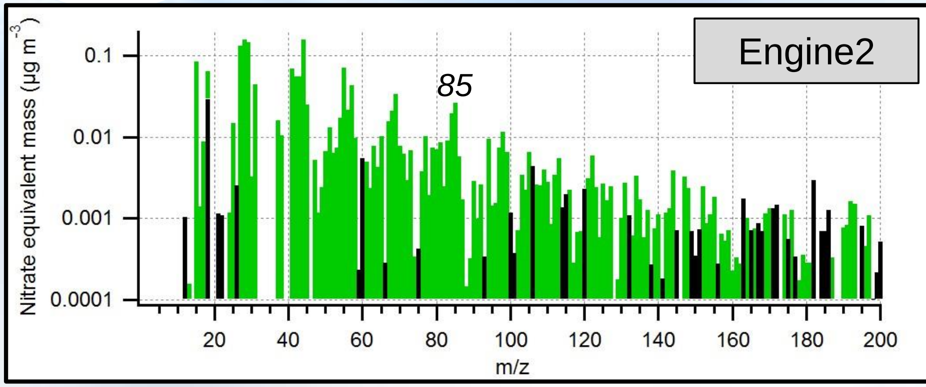


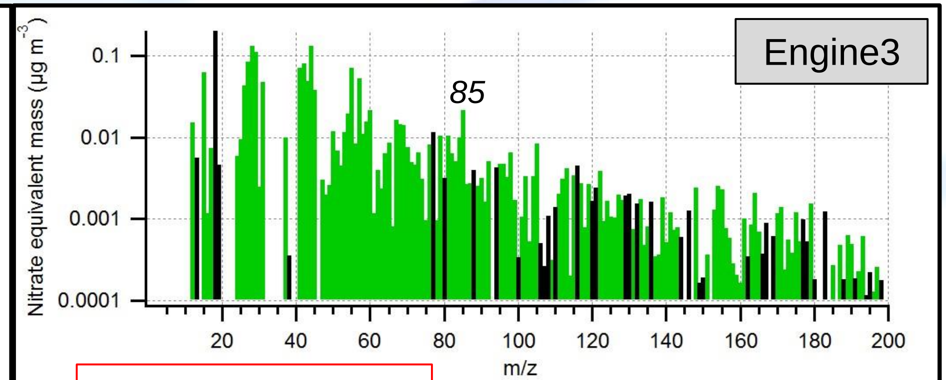


- No significant difference observed between fuels
- Oxygen content LOW compared to ambient aerosols

- Organic coatings are more oxidized for NON-contrail (clear) conditions
- Contrail may alter aerosol composition by removal of more-soluble compounds

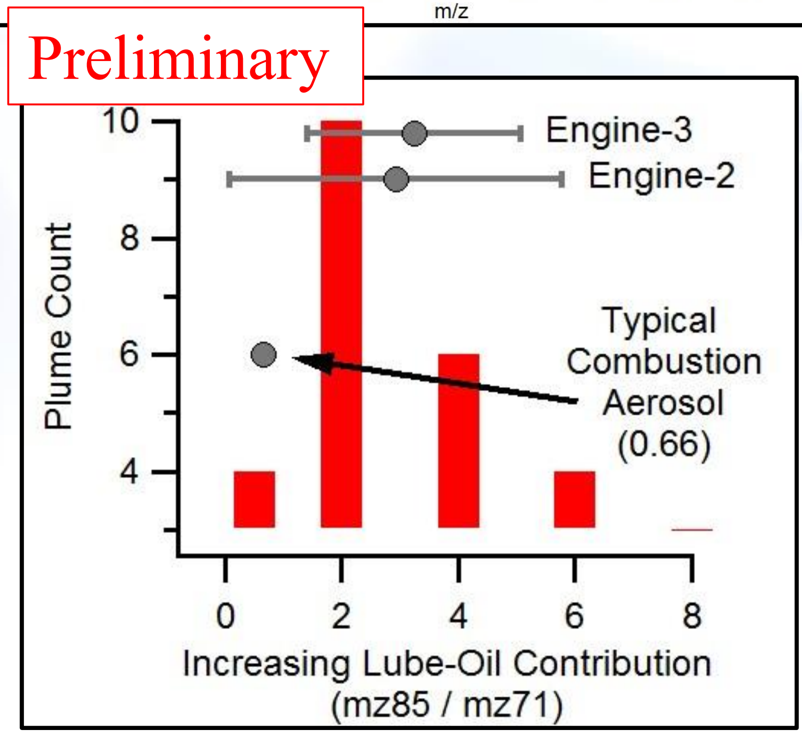
AMS Measurements: Lubrication Oil Contribution





Alkanes (combustion)	ExxonMobil Oil	BP Oil	ACCESS-II
0.66	**8.6**	**3.7**	**3.1**

- mz85/71 values >> 0.66 → lube-oils
- Data from all flights shows significant contribution throughout ACCESS-2
  - Must identify the oil used during ACCESS to quantify contribution
- Both engines exhibit similar lube-oil impacts



[*Yu et al. 2010, 2012*]

Conclusions and Future Work

1. The AMS technique is able to sufficiently resolve near-field aircraft emissions plumes
2. Measured volatile coatings are dominated by organic compounds
   - Low-sulfur HEFA and JetA fuels (11 and 8%) resulted in significantly less sulfate than High-S JetA fuel (30%)
3. Fuels had similar contribution from oxygenated compounds
   - Oxygenated (water-soluble) compounds may be preferentially removed in contrail conditions
4. Lubrication oil was likely a dominant fraction of measured organic mass

Thanks: NASA , ACCESS-II collaborators, LARGE team and aircraft crews!